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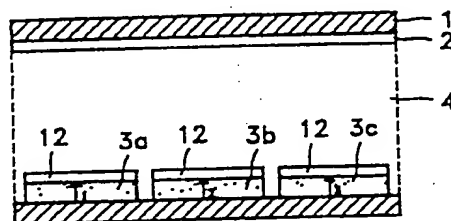(58) Field of Search
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(54) Ferroelectric liquid crystal display

(57) In the ferroelectric liquid crystal display device, a pixel region is divided into a plurality of sub-regions each having a predetermined size. A dielectric layer (3a, 3b, 3c) is formed to the same thickness atop or beneath each transparent electrode (12) of the separate sub-regions. Either the permittivity of the dielectric layers is similar and the optical transmittance thereof is different for each dielectric layer, or both permittivity and optical transmittance of the dielectric layers are different for each dielectric layer. The state of the ferroelectric liquid crystal corresponding to a specific sub-region may then be changed by using a voltage sharing method employing the principle of voltage drop by resistance. As a result, for each divided sub-region the transmittance can be varied relative to the others, so a gray scale display can be achieved with further fractionized gray scale levels.
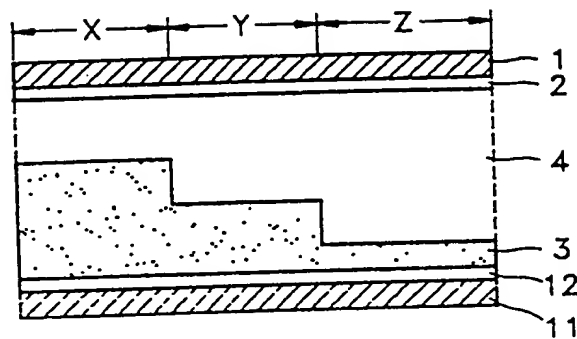
FIG.2B

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.
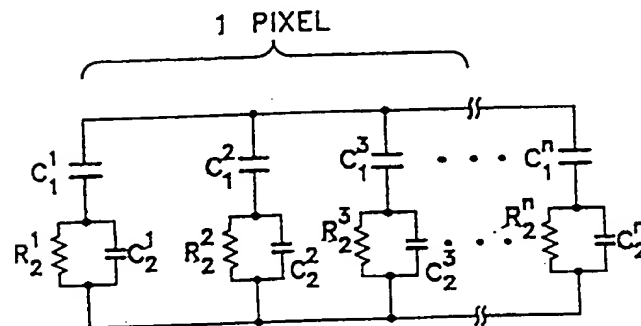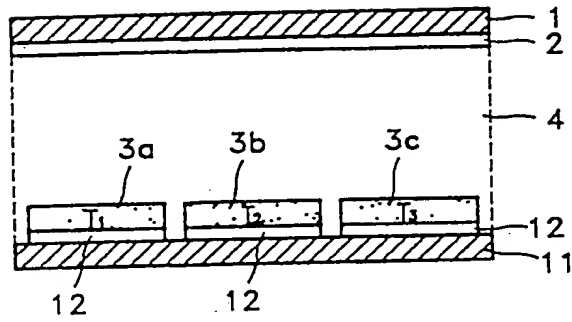
FIG.1A(PRIOR ART)

FIG.1B(PRIOR ART)

FIG.2A

FIG.2B
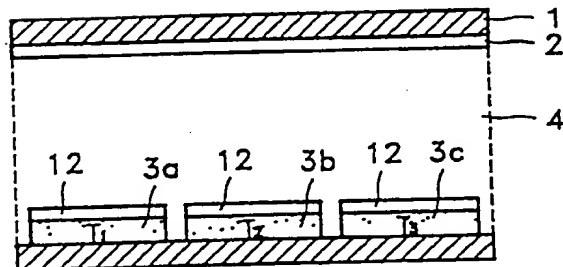
FIG.3A

FIG.3B

$a = \dfrac{b}{2}$

$b = \dfrac{c}{2}$

FIG.4

FIG.5A

ON
ON
ON

FIG.5B

ON
ON
OFF

FIG.5C

ON
OFF
OFF

FIG.5D

OFF
OFF
OFF
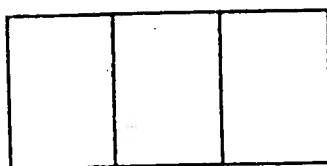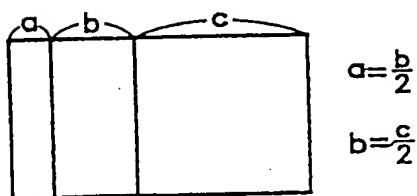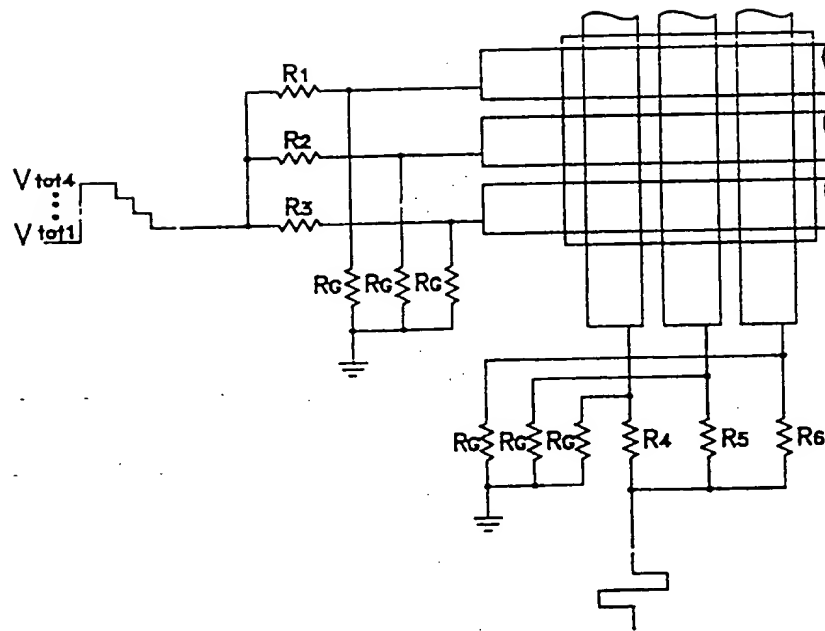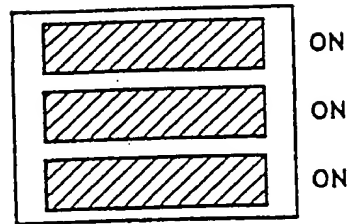
FERROELECTRIC LIQUID CRYSTAL DEVICE FOR GRAY SCALE DISPLAY, GRAY SCALE DISPLAY APPARATUS AND METHOD ADOPTING THE SAME

The present invention relates to a ferroelectric liquid crystal device for a gray scale display, preferably such that a totally even image can be provided, and a gray scale display apparatus and a method using such a ferroelectric liquid crystal device.

In a conventional ferroelectric crystal display device, only two states of black and white (off and on) can be displayed and gray-scale display is impossible.

FIG. 1A shows a vertical section of one example of a conventional ferroelectric crystal display device for solving such a problem. Refer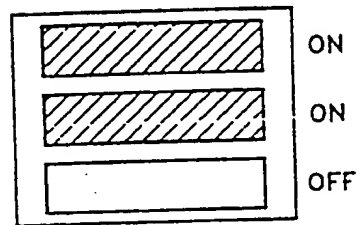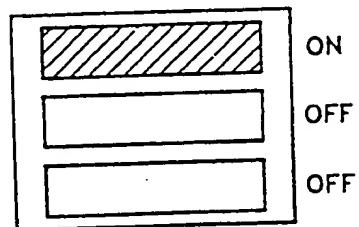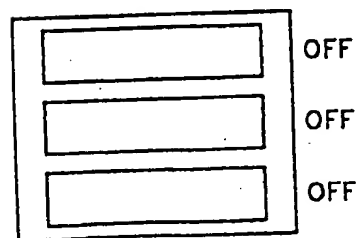ring to FIG. 1, the ferroelectric crystal display device comprises a pair of glass substrates 1 and 11, transparent electrodes 2 and 12, a ferroelectric liquid crystal layer 4, and a terraced insulating layer 3. As is well known, transparent electrodes 2 and 12 are comprised of indium-tin oxide (ITO), and liquid crystal layer 4 is comprised of various kinds of ferroelectric liquid crystals. Terraced insulating layer 3, which may be formed of polyamide resin, is placed on transparent electrode 12 formed on lower glass substrate 11, as shown in FIG. 1A. Each pixel region of the ferroelectric liquid crystal device is divided into three sub-regions X, Y and Z. Here, the thickness of pattern of terraced insulating layer 3 is different in each of sub-regions X, Y and Z, so that sub-regions X, Y and Z provide capacitances C_2^1, C_2^2 and C_2^3, respectively, as shown in FIG. 1B.

Similarly, if the capacitances and resistance values with respect to each pixel sub-region of the liquid crystal layer 4 are represented as C_1^1, C_1^2 and C_1^3, ... and R_2^1, R_2^2 and R_2^3, ...

the ferroelectric liquid crystal device can be represented as an equivalent circuit as shown in FIG. 1B. Here, the number of pixel regions is generalized as n.

Also, in cases such that all pixel sub-regions have the same area and ferroelectric liquid crystal layer 4 is much thicker than terraced insulating layer 3, the capacitance and resistance values with respect to each pixel region of the ferroelectric liquid crystal device can be approximated as: $C_1^1 \approx C_1^2 \approx C_1^3$, and

$R_2^1 \approx R_2^2 \approx R_2^3$. The voltage applied to liquid crystal layer 4 is then

essentially a function of the capacitances C_2^1, C_2^2 and C_2^3, ...

of terraced insulating layer 3.

According to the conventional approach described above, the thickness of the insulating layer between upper and lower plates is set to vary within a pixel in an arbitrary manner and only the liquid crystal corresponding to a specific region in the insulating layer is selectively driven for the gray scale display. That is, gray-scale display is achieved using the difference of the optical transmittance according to the difference in the thickness of the insulating layer.

However, in the above gray scale display, the thickness of the liquid crystal layer is varied due to the different thickness of the insulating layer within a pixel, so that the light

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intensity transmitting the liquid crystal layer is not uniform within a pixel. As a result, the image (luminance) is not uniform within a pixel.

To solve the above problem, it is an object of the present invention to provide a ferroelectric liquid crystal display device for a gray scale display, in which the thickness of a liquid crystal layer remains uniform so as to provide a uniform luminance in a pixel, and further to provide a gray scale display apparatus, and a method, using the ferroelectric liquid crystal display device.

Accordingly, the invention provides a ferroelectric liquid crystal display device comprising: first and second substrates which oppose each other with a predetermined spacing; a first transparent electrode formed on the inner surface of the first substrate; a plurality of second transparent electrodes formed on the inner surface of the second substrate with respect to each pixel, each having a predetermined width; a plurality of dielectric layers formed on the plurality of second transparent electrodes, with the same thickness and having different optical transmittances; and a ferroelectric liquid crystal layer formed between the second substrate on which the dielectric layers are formed and the first substrate having the first transparent electrode thereon.

The invention further provides a ferroelectric liquid crystal display device comprising: first and second substrates which oppose each other with a predetermined spacing; a first transparent electrode formed on the inner surface of the first substrate; a plurality of dielectric layers formed on the inner

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surface of the second substrate with respect to each pixel with the same thickness and having different optical transmittances; a plurality of second transparent electrodes formed on the dielectric layers; and a ferroelectric liquid crystal layer formed between the second substrates on which the second transparent electrodes are formed and the first substrate having thereon the first transparent electrode.

It is preferable that the dielectric layers and the second transparent electrodes have the same width.

Moreover, the invention provides a gray scale display apparatus comprising: a liquid crystal display device having a plurality of transparent electrodes formed on the inner surface of one of first and second substrates opposing each other with a predetermined spacing, with respect to each pixel, and a plurality of dielectric layers formed on the transparent electrodes with the same thickness and having different optical transmittance; and a signal voltage dividing means for dividing a signal voltage applied to the terminals of the transparent electrodes so as to provide signals having different voltage levels.

Preferably, the signal voltage dividing means divides the signal voltage by connecting a predetermined number of resistors to each terminal of the transparent electrodes in each pixel.

The invention still further provides a gray scale display method in a gray scale display apparatus comprising a plurality of transparent electrodes formed on the inner surface of one of first and second substrates opposing each other with a predetermined spacing with respect to each pixel, a plurality of

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dielectric layers formed on the transparent electrodes with the same thickness and having different optical transmittances, and signal voltage dividing means for dividing a signal voltage applied to the terminals of the transparent electrodes so as to provide signals having different voltage levels, comprising the steps of: dividing the applied signal voltage using the signal voltage dividing means connected to the transparent electrodes; and displaying a gray scale by driving the transparent electrodes when the voltage divided by the signal voltage dividing means is not less than a predetermined threshold voltage.

Specific embodiments of the invention are described below, by way of example, with reference to the attached drawings in which:

FIG. 1A is a vertical section view of a conventional ferroelectric liquid crystal display device for a gray scale display;

FIG. 1B is an electrical equivalent circuit diagram of the ferroelectric liquid crystal display device shown in FIG. 1A;

FIG. 2A is a vertical section view of a ferroelectric liquid crystal display device for the gray scale display according to a preferred embodiment of the present invention;

FIG. 2B is a vertical section view of a ferroelectric liquid crystal display device for the gray scale display according to another preferred embodiment of the present invention;

FIG. 3A is a diagram for illustrating a first pixel dividing method of the ferroelectric liquid crystal display devices shown in FIGS. 2A and 2B;

FIG. 3B is a diagram for illustrating a second pixel

dividing method of the ferroelectric liquid crystal display devices shown in FIGS. 2A and 2B;

FIG. 4 is a circuit diagram of a gray scale display apparatus adopting the ferroelectric liquid crystal display device according to preferred embodiments of the present invention; and

FIGS. 5A-5D are diagrams for illustrating the gray-scale display methods in the gray scale display apparatus according to preferred embodiments of the present invention.

In order to achieve a gray scale display while maintaining the thickness of a liquid crystal layer constantly, each pixel of a ferroelectric liquid crystal display device is divided into a plurality of sub-regions and then each separate sub-region is driven after an electrode is formed thereon, or dielectric layers having different permittivity are formed on the electrodes so that the effective capacitance becomes different in each sub-region. As a result, the applied signal voltage achieves a different response in each separate sub-region, thereby enabling display of a gray scale. Alternatively, dielectric layers each having similar permittivity and different optical transmittance may be formed on each electrode formed on the separate sub-regions, thereby achieving the gray scale display.

However, as pixel is divided into many sub-regions each of which are driven by electrodes, an expensive driving circuit results. Also, it is relatively difficult to form evenly dielectric layers having different permittivity so as to drive the divided sub-regions of each pixel with different capacitances. Therefore, according to preferred embodiments of

the present invention, the gray scale is displayed using the ferroelectric liquid crystal display device in which the dielectric layers each having similar permittivity and different optical transmittance are formed.

The structure of the ferroelectric liquid crystal display device according to an embodiment the present invention will be described with reference to FIG. 2A.

As shown in FIG. 2A, a front glass substrate 1 and a rear glass substrate 11 are placed to oppose each other a predetermined distance apart, and first and second transparent electrodes 2 and 12 are formed on the opposing surfaces of front and rear glass substrates, respectively. In this example, second transparent electrode 12 is formed to have three divisions in each pixel region, so three dielectric layers 3a, 3b and 3c which have similar permittivity and different optical transmittances T_1, T_2 and T_3 are formed with the same thickness on second transparent electrode 12 divided into three. The space formed between rear glass substrate 11, on which dielectric layers 3a, 3b and 3c are formed, and front glass substrate 1, below which first transparent electrode 2 is formed, is filled with a liquid crystal 4.

In a ferroelectric liquid crystal display device having the above structure, the provision in the manner described above of three dielectric layers 3a, 3b and 3c which have similar permittivity and different optical transmittance allows eight (2^3) gray scales to be displayed through an appropriate circuit combination of the three dielectric layers 3a, 3b and 3c.

FIG. 2B is a vertical section view of a ferroelectric liquid

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crystal display device for gray scale display according to another preferred embodiment of the present invention. In this embodiment, the stacking sequence of the second transparent electrode 12 and dielectric layers 3a, 3b and 3c on the rear glass substrate is the opposite of that in the ferroelectric liquid crystal display device shown in FIG. 2A. The gray scale display method and the number of circuit combinations are the same as for the ferroelectric liquid crystal display device shown in FIG. 2A.

For a ferroelectric liquid crystal display device having the structure above, the pixel region is divided into a plurality of sub-regions, each having an arbitrary size, and dielectric layers having similar permittivity and different optical transmittance are formed on the portions of the first or second transparent electrode corresponding to the separate sub-regions with the same thickness. The state of the ferroelectric liquid crystal corresponding a specific sub-region is then changed using a voltage sharing method employing the principle of 'voltage drop by resistance, so that for each divided sub-region the transmittance can be varied relative to the other. As a result, the level of the gray scale can be fractionized.

For example, as shown in FIG. 3A, when the dielectric layers, each having different permittivity, are divided evenly, the gray level is not discriminated between divided sub-regions, so that only four gray levels (all sub-regions on, two sub-regions on, one sub-region on, all sub-regions off) can be expressed. However, as shown in FIG. 3B, when the dielectric layers are divided unevenly, the gray level is discriminated

between the divided sub-regions. Thus, eight (2^3) gray levels can be expressed by combining each gray level of the divided sub-regions.

However, if the optical transmittance of each evenly divided dielectric layer of FIG. 3A is different, the lightness between the sub-regions is discriminated, so that eight gray levels can be expressed as for the case of FIG. 3B. Also, dividing the dielectric layer evenly is advantageous for the manufacturing process. In such a case, if a relative transmittance of region a is 100%, the relative transmittance values of b and c may be 50% and 25%, respectively.

A gray scale display apparatus and method adopting the ferroelectric liquid crystal display device according to embodiments of the present invention will be described with reference to FIGS. 4 and 5A-5D.

As shown in FIG. 4, according to the gray scale display apparatus of embodiments of the present invention, each pixel region of the ferroelectric liquid crystal display device is divided into nine sub-regions. Here, each pixel region is provided with three column and row electrodes, wherein resistors are connected to the ends of column and row electrodes, respectively, thereby dividing the signal voltage applied to the electrodes. In this case, as shown in FIG. 4, resistors R_1, R_2, R_3 and R_G, which each have different resistance values are connected to the ends of the column electrodes, and resistors R_4, R_5, R_6 and R_G, which each have different resistance values, are connected to the ends of the row electrodes. The other end of each resistor is connected to a main signal terminal.

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The voltage level of the signal input to each main signal terminal is set to four levels, and the voltage input to each electrode, which is dropped via each resistor, is adjusted to be over threshold voltage V_{th} which affects the state of the liquid crystal.

In the example shown in FIGS. 5A-5D, when the voltage (total voltage $V_{tot1} \sim V_{tot4}$) of the main signal terminal is divided and then applied to each column electrode as indicated below, each sub-region of the pixel is driven partially to a degree determined by how the conditions of the following table are satisfied. As a result, a gray scale display can be achieved. That is, the voltage level of the applied main signal is divided by the resistors, each of which are connected to three transparent electrodes of each pixel. Each sub-region of the pixel is driven or not according to whether the divided voltage level is more than or equal to the threshold voltage, thereby displaying the gray scale.

No.	condition	resulting gray-scale display state	FIGURE
1	$V_{tot4} - I_1R_1 = V_1 \geq V_{th}$ $V_{tot4} - I_2R_2 = V_2 \geq V_{th}$ $V_{tot4} - I_3R_3 = V_3 \geq V_{th}$	ON-ON-ON	6A
2	$V_{tot3} - I_1R_1 = V_1 \geq V_{th}$ $V_{tot3} - I_2R_2 = V_2 \geq V_{th}$ $V_{tot3} - I_3R_3 = V_3 < V_{th}$	ON-ON-OFF	6B
3	$V_{tot2} - I_1R_1 = V_1 \geq V_{th}$ $V_{tot2} - I_2R_2 = V_2 < V_{th}$ $V_{tot2} - I_3R_3 = V_3 < V_{th}$	ON-OFF-OFF	6C

4	$V_{tot1} - I_1R_1 = V_1 < V_{th}$ $V_{tot1} - I_2R_2 = V_2 < V_{th}$ $V_{tot1} - I_3R_3 = V_3 < V_{th}$	OFF-OFF-OFF	6D

Also, if the voltage level of the signal applied to the row electrodes is adjusted in the same manner as above, more gray scales can be displayed.

As described above, in a ferroelectric liquid crystal display device, and gray scale display apparatus and method using the same, according to preferred embodiments of the present invention, a pixel region is divided into a plurality of sub-regions, each having an arbitrary size, a dielectric layer is formed to the same thickness either atop or beneath each transparent electrode corresponding to a divided sub-region, respectively, wherein the permittivity of the dielectric layers is similar and the optical transmittance thereof is different, or alternatively, both permittivity and optical transmittance of the dielectric layers are different. This enables the state of the ferroelectric liquid crystal corresponding to each sub-region to be changed selectively using a voltage sharing method adopting the principle of voltage drop by resistance. As a result, the lightness of each separate sub-region can be varied individually, so that a gray scale display can be achieved with further fractionated gray scale levels. Accordingly, a gray scale can be effectively displayed without any unevenness of the displayed screen caused by the difference in thickness of the ferroelectric liquid crystal layer within a pixel.

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CLAIMS:

1. A ferroelectric liquid crystal display device comprising:

first and second substrates which oppose each other with a predetermined spacing therebetween;

5   a first transparent electrode formed on an inner surface of said first substrate;

a plurality of second transparent electrodes formed on an inner surface of said second substrate with respect to each pixel, each of said second transparent electrodes having a

10   predetermined width;

a plurality of dielectric layers formed on said plurality of second transparent electrodes, each of said dielectric layers having the same thickness but having different optical transmittances; and

15   a ferroelectric liquid crystal layer formed between said second substrate on which said dielectric layers are formed and said first substrate on which said first transparent electrode is formed.

2. A ferroelectric liquid crystal display device

20   comprising:

first and second substrates which oppose each other with a predetermined spacing therebetween;

a first transparent electrode formed on an inner surface of said first substrate;

25   a plurality of dielectric layers formed on an inner surface of said second substrate with respect to each pixel, each of said dielectric layers having the same thickness but having different optical transmittances;

a plurality of second transparent electrodes formed on said dielectric layers; and

a ferroelectric liquid crystal layer formed between said second substrates on which said second transparent electrodes are formed and said first substrate on which said first transparent electrode is formed.

3. A ferroelectric liquid crystal display device as claimed in claim 1 or claim 2, wherein said dielectric layers and said second transparent electrodes have the same width.

4. A gray scale display apparatus comprising:

a liquid crystal display device having a plurality of transparent electrodes formed on the inner surface of one of first and second substrates opposing each other with a predetermined spacing therebetween, with respect to each pixel, and a plurality of dielectric layers formed on said transparent electrodes, said dielectric layers having the same thickness but having different optical transmittances; and

a signal voltage dividing means for dividing a signal voltage applied to the terminals of said transparent electrodes so as to provide signals having different voltage levels.

5. A gray scale display apparatus comprising:

a ferroelectric liquid crsytal display as claimed in any of claims 1 to 3; and

a signal voltage dividing means for dividing a signal voltage applied to the terminals of said transparent electrodes so as to provide signals having different voltage levels.

6. A gray scale display apparatus as claimed in claim 4 or claim 5, wherein said signal voltage dividing means divides the

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signal voltage by connecting a predetermined number of resistors to each terminal of said transparent electrodes in each pixel.

7. A gray scale display method for use in a gray scale display apparatus as claimed in any of claims 4 to 6, comprising the steps of:

dividing the applied signal voltage using said signal voltage dividing means connected to said transparent electrodes; and

displaying a gray scale by driving said transparent electrodes when the voltage divided by said signal voltage dividing means is not less than a predetermined threshold voltage.

8. A ferroelectric liquid crystal display substantially as herein described with reference to Figures 2 to 5 of the accompanying drawings.

9. A gray scale display apparatus substantially as herein described with reference to Figures 2 to 5 of the accompanying drawings.

10. A gray scale display method substantially as herein described with reference to Figures 2 to 5 of the accompanying drawings.

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